DOCUMENT RESUME

ED 474 456 SE 067 421

AUTHOR	Hake, Richard R.
TITLE	Towards Paradigm Peace in Physics Education Research.
SPONS AGENCY	National Science Foundation, Arlington, VA.
PUB DATE	2000-00-00
NOTE	19p.
AVAILABLE FROM	web site: http://www.physics.indiana/edu/~hake/ and http://www.physics.indiana.edu/~sdi.
PUB TYPE	Opinion Papers (120) -- Speeches/Meeting Papers (150)
EDRS PRICE	EDRS Price MF01/PC01 Plus Postage.
DESCRIPTORS	*Educational Research; *Physics; Research Methodology; Science Education

ABSTRACT

This paper summarizes two examples in order to predict which of Gage's three scenarios about possible histories of education research will occur. A prediction of educational research for the year 2009 is also made. (KHR)

Reproductions supplied by EDRS are the best that can be made
from the original document.

ED 474 456

Towards Paradigm Peace In Physics Education Research*†

RICHARD R. HAKE

In his address "The Paradigm Wars and Their Aftermath," delivered over a decade ago at the annual AERA meeting in San Francisco, Gage (1989) foresaw three possible histories of education research as written in 2009:

> *(1) Raging in the 1980's, the Paradigm Wars resulted in the demise of objectivity-seeking quantitative research on teaching - a victim of putatively devastating attacks from anti-naturalists, interpretivists, and critical theorists.*
>
> *(2) Thus from the jungle wars of the 1980's, educational researchers, including those concerned with teaching, emerged into a sunlit plain - a happy and productive arena in which the strengths of all three paradigms (objective-quantitative, interpretive-qualitative, and critical-theoretical) were abundantly realized, with a corresponding decrease in the harmful effects of their respective inadequacies.*
>
> *(3) What happened after 1989 in research in teaching was pretty much the same as what happened before 1989. The invective and vituperation continued.*

With the benefit of another decade of experience, it may be worthwhile to attempt to predict which (if any) of Gage's three scenarios will occur. I think that harbingers of 2009 exist in current physics-education research (PER) (Redish, 1999; McDermott & Redish, 1999). This paper summarizes two examples and then gives a prediction.

---

*Presented at the annual meeting of the *American Educational Research Association*, New Orleans, April 24-28, 2000. Comments and criticisms will be welcomed at R.R. Hake, 24245 Hatteras Street, Woodland Hills, CA, 91367, USA; e-mail <rrhake@earthlink.net>. This and other related papers are on the web at < http://www.physics.indiana.edu/~hake > and < http://www.physics.indiana.edu/~sdi >.

†This work received partial support from NSF Grant DUE/MDR9253965.

© Richard R. Hake, 4/23/00. Permission to copy or disseminate all or part of this material is granted provided that the copies are not made or distributed for commercial advantage, and the copyright and its date appear. To disseminate otherwise, to republish, or to place at another website (instead of linking to < http://www.physics.indiana.edu/~sdi >) requires written permission.

PERMISSION TO REPRODUCE AND DISSEMINATE THIS MATERIAL HAS BEEN GRANTED BY

R. Hake

TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)

BEST COPY AVAILABLE

1

2

U.S. DEPARTMENT OF EDUCATION
Office of Educational Research and Improvement
EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)

☒ This document has been reproduced as received from the person or organization originating it.

☐ Minor changes have been made to improve reproduction quality.

• Points of view or opinions stated in this document do not necessarily represent official OERI position or policy.

3E067421

Example 1. Quantitative Research: A Meta-Analysis

Data from a survey (Hake, 1998a,b,d; 2000) of pre/post data using standard tests of conceptual understanding, recognized for high reliability and validity [Halloun-Hestenes *Mechanics Diagnostic* test (Halloun & Hestenes, 1985) or the more recent *Force Concept Inventory* (Hestenes, Wells, Swackhamer, 1992; Halloun, Hake, Mosca, Hestenes, 1995)] for 62 introductory physics courses enrolling a total number of students N = 6542, are shown in Fig. 1. Starting in 1992, I requested that pre-/post-FCI data and post-test Mechanics Baseline (a problem-solving test due to Hestenes & Wells, 1992) data be sent to me. Since instructors are more likely to report higher-gain courses, the detector is biased in favor of those courses, but can still answer a crucial research question: *Can the use of Interactive Engagement (IE) methods increase the effectiveness of introductory mechanics courses well beyond that obtained by traditional methods?*

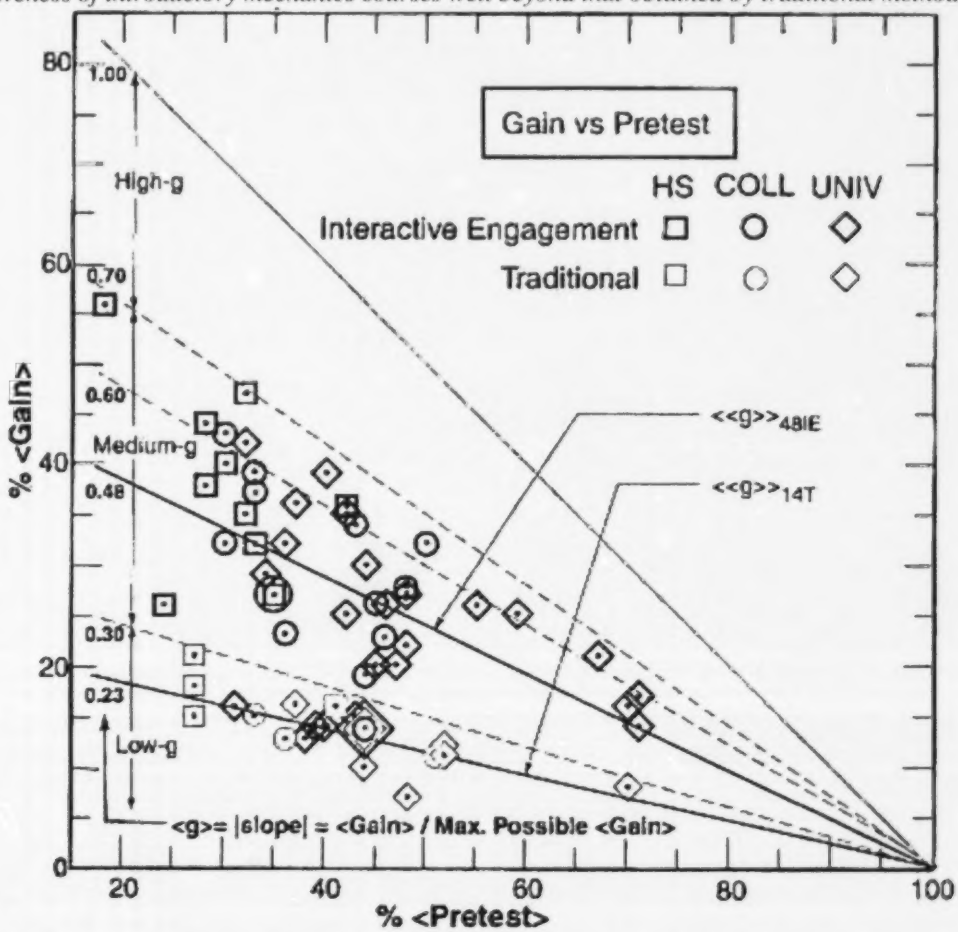


Fig. 1. The %<Gain> vs %<Pretest> score for 62 courses enrolling a total of N = 6542 students. Slope lines $\langle\langle g\rangle\rangle_{14T}$ for the average of the 14 T courses and $\langle\langle g\rangle\rangle_{48IE}$ for the average of the 48 IE courses are shown, as explained in the text. (From Hake, 1998a.)

BEST COPY AVAILABLE

A histogram of the data of Fig. 1 is shown in Fig. 2.

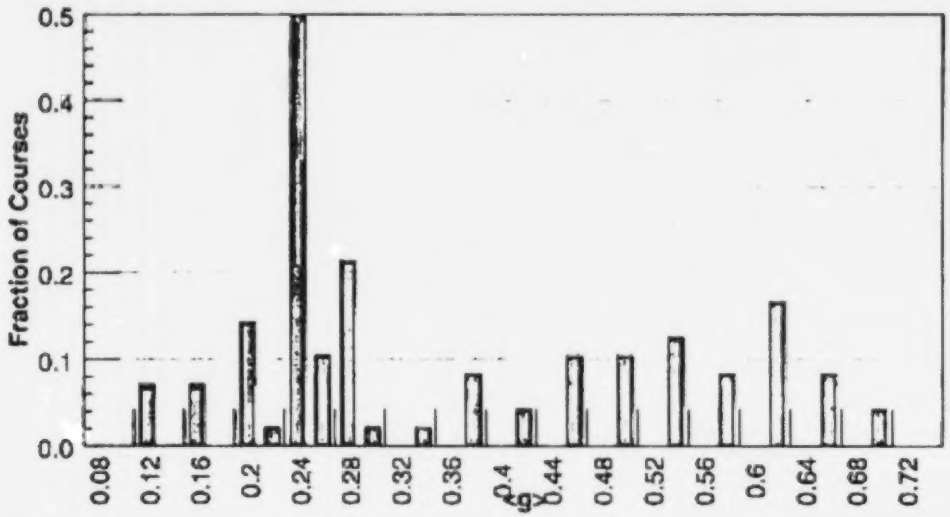


Fig. 2. Histogram of the average normalized gain <g>: red bars show the fraction of 14 Traditional (T) courses (N = 2108) and green bars show the fraction of 48 Interactive Engagement (IE) courses (N = 4458), both within bins of width Δ<g> = 0.04, centered on the <g> values shown. (From Hake, 1998a.)

The data of Figs. 1 and 2 show that:

a. A consistent analysis over diverse student populations in high schools, colleges, and universities is obtained if a rough measure of the average effectiveness of a course in promoting conceptual understanding is taken to be the average normalized gain <g>. The latter is defined as the ratio of the *actual* average gain (%<Gain>) = (%<posttest> - %<pretest>) to the maximum possible average gain (%<$Gain_{max}$>) = (100 - %<pretest>). It should be noted that for any particular course C' with course point [(%<Gain>') , (%<pretest>')] on Fig. 1, the *absolute value of the slope* of a line connecting the C' course point with the point [(%<Gain>) = 0, (%<pretest>) = 100] is just the normalized gain <g>' for course C'. Thus other courses C lying on that same line all have the same normalized gain <g>' as course C' and are thus of equal average effectiveness. The maximum possible normalized gain $\langle g \rangle_{max}$ = 1.0 is represented by the 45 degree negative slope line in Fig. 1.

b. Traditional (T) courses (passive-student lectures, recipe labs, and algorithmic-problem exams) fail to convey much conceptual understanding to the average student, yielding an average of the average <g>'s for 14 courses (N = 2048) of $\langle\langle g \rangle\rangle_{14T}$ = 0.23 ± 0.04sd, where sd stands for standard deviation. The slope line $\langle\langle g \rangle\rangle_{14T}$ is shown in Fig. 1.

BEST COPY AVAILABLE

c. Interactive-engagement (IE) courses can be much more effective than T courses in enhancing conceptual understanding. Here "IE courses" are defined operationally as those reported by instructors to make substantial use of "IE methods." The latter are operationally defined as *methods designed at least in part to promote conceptual understanding through interactive engagement of students in heads-on (always) and hands-on (usually) activities that yield immediate feedback through discussion with peers and/or instructors, all as judged by their literature descriptions*. The 48 IE courses of the survey (N = 4458), yield $\langle\langle g\rangle\rangle_{48IE} = 0.48 \pm 0.14$sd. This is over twice that of $\langle\langle g\rangle\rangle_{14T}$, and is almost two sd's of $\langle\langle g\rangle\rangle_{48IE}$ above that of the T courses, reminiscent of differences seen in comparing instruction delivered to students in large groups with one-on-one instruction. (Bloom, 1984) The slope line $\langle\langle g\rangle\rangle_{48IE}$ is shown in Fig. 1.

d. Current IE methods need to be improved, since none of the IE courses achieves <g> greater than 0.69. In fact, as can be seen in Fig. 1, seven of the IE courses (N = 717) achieved <g>'s ranging from 0.21 to 0.26, characteristic of T courses. It would seem that (contrary to the suggestion of Greene, 1999) it takes more than just an emphasis on concepts to induce high <g>. Case histories of the seven low-<g> courses (Hake, 1998b) suggest that implementation failures occurred that might be mitigated by:

(1) apprenticeship education of instructors new to IE methods,

(2) emphasis on the nature of science and learning throughout the course,

(3) careful attention to motivational factors and the provision of grade incentives for taking IE activities seriously,

(4) recognition of and positive intervention for potential low-gain students,

(5) administration of exams in which a substantial number of the questions probe the degree of conceptual understanding induced by the IE methods,

(6) use of IE methods in all components of a course and tight integration of those components.

e. The correlation of the average normalized gain <g> with (%<pretest>) for the 62 courses of Fig. 1 is a very low +0.02. This constitutes an experimental justification for the use of <g> as a comparative measure of course effectiveness over diverse student populations with widely varying average pretest scores. In contrast, the average posttest score (%<posttest >) and the average actual gain (%<Gain>) are less suitable for comparing course effectiveness over diverse groups since the correlation of:

(%<posttest>) with (%<pretest>) is + 0.55, and

(%<Gain>) with (%<pretest>) is – 0.49,

as is reasonable. Note that in the *absence* of instruction, a high positive correlation of (%<post >) with (%<pre>) would be expected.

f. Fig. 3 shows the average course scores on the problem-solving Mechanics Baseline test (Hestenes & Wells, 1992) [available for 30 (N = 3259) of the 62 courses of the survey] vs those on the conceptual FCI. There is a strong positive correlation r = + 0.91 of the MB and FCI scores. This correlation and the comparison of IE and T courses at the same institution (Hake, 1998a) imply that *IE methods enhance problem-solving ability*.

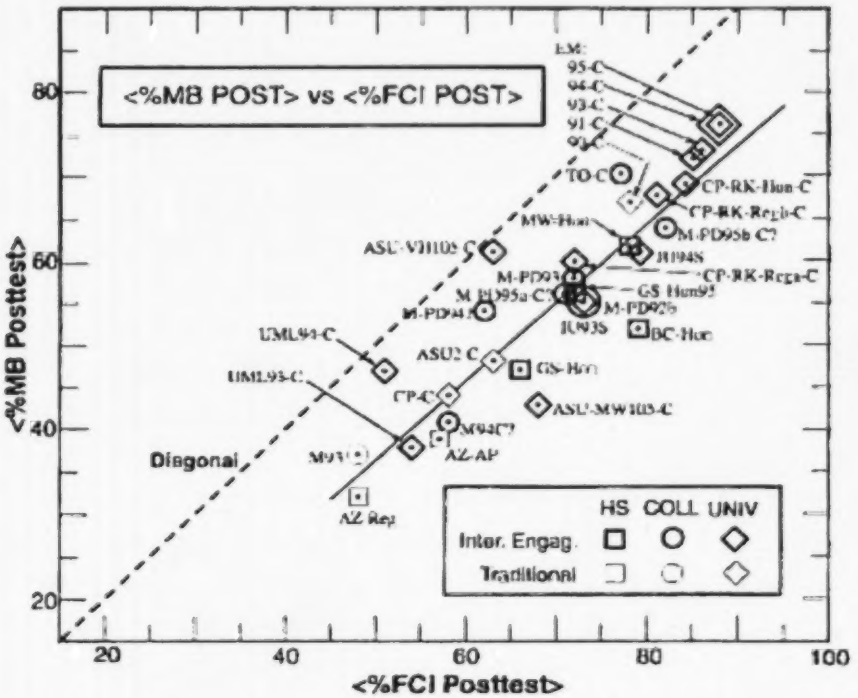


Fig. 3. Average posttest scores on the problem-solving Mechanics Baseline (MB) test vs those on the conceptual FCI test for all courses of the survey for which data are available: thirty courses (high school, college, and university) which enroll a total N = 3259 students. The solid line is a least-squares fit to the data points. The dashed line is the diagonal representing equal scores on the MB and FCI tests. (From Hake, 1998a.)

g. An analysis (Hake, 1999a) of survey results in terms of the "effect size" <d> so commonly used in meta-analyses (Cohen, 1988; Hunt, 1997) has been carried out. Here <d> is defined as the ratio of the actual average gain (%<post> - %<pre>) to the average of the sd's. I obtain an average <d> = 0.88 for 9 T courses (N = 1620), and an average <d> = 2.18 for 24 IE courses (N = 1843) for which sd's are available. The latter can be compared with: (1) the similar <d> = 1.91 reported by Zeilik, Schau, Mattern (1998) for a single IE introductory astronomy course (N = 221) given in Spring 1995 at the University of New Mexico, and (2) the much smaller average <d> = 0.51 obtained in a meta-analysis of small-group learning by Springer, Stanne, Donovan (1999). In the Springer study, as for much research

BEST COPY AVAILABLE

reported in the educational literature, (a) in many cases there was no pretesting to disclose initial knowledge states of the test or control groups, (b) the quality of the "achievement tests" was not critically examined (were they of the plug-in-regurgitation type so common in introductory physics courses?). I think that the Springer et al. meta-analysis probably understates the effectiveness of cooperative learning in advancing conceptual understanding and problem-solving ability.

h. A detailed analysis of random and systematic errors has been carried out (Hake, 1996, 1998a)

Random Error: Because the difference in $\langle\langle g \rangle\rangle_{IE48} - \langle\langle g \rangle\rangle_{T14} = 0.25$ is equal to 1.8 SD's of the $\langle g \rangle_{IE}$ distribution and 6.2 SD's of the $\langle g \rangle_{T}$ distribution, the probability that the difference could be due to chance is extremely small. The conventional statistical analysis (Slavin, 1992; Snedecor & Cochran, 1989, p. 83-102) yields: $t = 11$; $df = 60$, where df is the "degrees of freedom"; and $p < 0.001$, where p is the two-tailed probability, p, that the means difference is due to chance. I assume that the t-test is approximately valid, even though the <g> distributions (Fig. 2) are skewed. [Because the variances of the <g> distributions for the IE and T courses are markedly dissimilar ($F = 12$), I have employed an approximation to the standard t-test due to Satterthwaite as discussed by Snedecore & Cochran, 1998, p. 97.]

As discussed by Hake (1998d), physicist Robert Ehrlich thought that "…. the size of the sample Hake used for the traditional courses was fairly small, so a statistical fluctuation was always a possibility" (private communication). Testing his conjecture, Ehrlich elicited pre/post FCI testing in 12 more-or-less traditional courses taught by instructors with whom he was acquainted. These yielded an average normalized gain $\langle\langle g \rangle\rangle = 0.20 \pm 0.06$sd, consistent with my survey results for 14 T courses.

Considering all the above, it is extremely unlikely that random error plays a significant role in the nearly two-standard- deviation difference of the T and IE courses.

Systematic Error: The following systematic errors have been examined and arguments (not repeated here) have been advanced (Hake, 1998a) for their probable insignificance: (a) Question ambiguities and isolated false positives. (b) Teaching to the test and test-question leakage. (c) Varying fraction of course time spent on mechanics among the courses of the survey. (d) Varying post and pretest motivation of students among the courses of the survey. (e) Hawthorne/John Henry effects. Thus it is extremely unlikely that systematic error plays a significant role in the nearly two-standard-deviation difference of the T and IE courses.

Considering points "a" - "h" above, the results of the survey (Hake, 1998a) can be summarized as follows:

a. Fourteen T courses (N = 2084) which made little or no use of IE methods achieved an average normalized gain $\langle\langle g \rangle\rangle = 0.23 \pm 0.04$sd. In sharp contrast, 48 IE courses (N = 4458) that made substantial use of IE methods achieved an average gain $\langle\langle g \rangle\rangle = 0.48 \pm 0.14$sd. *It is extremely unlikely that random or systematic error plays a significant role in the nearly two-standard deviation difference of the T and IE courses.*

b. A plot of average course scores on the problem-solving Mechanics Baseline (MB) test vs those on the conceptual Force Concept Inventory (FCI) show a strong positive correlation $r = + 0.91$. This correlation and direct comparison of IE and T courses at the same institution imply that *IE methods enhance problem-solving ability.*

c. The above conceptual and problem solving test results strongly suggest that ***the use of IE strategies can increase mechanics-course effectiveness well beyond that obtained with traditional methods***. However, IE strategies and their implementation need to be improved.

Results consistent with those of the survey have now been obtained by physics-education research groups at the Univ. of Maryland (Redish, Saul, Steinberg, 1997; Saul, 1998; Redish & Steinberg, 1999; Redish, 1999); Univ. of Montana (Francis, Adams, Noonan, 1998); Rennselaer and Tufts (Cummings, Marx, Thornton, Kuhl, 1999); North Carolina State Univ. (Beichner, Bernold, Burniston, Dail, Felder, Gastineau, Gjertsen, Risley, 1999); and Hogskolan Dalarna - Sweden (Bernhard, 1999). Thus in PER, just as in hard-core traditional physics research, it is possible to perform quantitative experiments which can be reproduced (or refuted) by other investigators and thus contribute to the construction of a "community map." (Redish, 1999).

Example 2. Quantitative Research: "Pinning a Kid To Her Seat"

The number of IE courses using each of the more popular methods is - Collaborative Peer Instruction: 48 (all courses); Microcomputer-Based Labs: 35; Concept Tests: 20; Modeling: 19; Active Learning Problem Sets or Overview Case Studies: 17; and Socratic Dialogue Inducing (SDI) Labs: 9. (Of course, relative popularity has no necessary connection with relative merit - in fact, considering that SDI labs came in *last* in popularity, there may well be a *negative* correlation between merit and popularity!) For references to these and other IE methods see Hake, 1998a, 1998b.

As discussed by Hake (1991) Socratic Dialogue Inducing (SDI) labs (Hake, 1987; Tobias & Hake, 1988; Hake, 1992) were originally inspired by the work of Arons (1990) whose empirically-based ideas are consistent with much of the recent work in cognitive science (Bransford, Brown, Cocking, 1999). Although the Socratic method as portrayed in the *Meno* (Plato, 380 B.C.; Jowett, 1953) has been dismissed by some influential physics teachers (Swartz, 1994, 2000; Morse, 1994), it should be emphasized that the Socratic method used so successfully by myself and other physics instructors (see, e.g., Arons, 1990; McDermott, Shaffer, and Somers, 1994; Wells & Hestenes, 1995; Redish, Saul, and Steinberg, 1997) is derived *not* from the *fictional* Socrates of Plato's imagination as depicted in the *Meno*, but rather from the *real* historical Socrates as researched by the late great Gregory Vlastos (Vlastos, 1990, 1991, 1994). Vlastos (1990) wrote to me:

> *I only wish I had been taught physics in the way you propose .... Though Socrates was not engaged in physical inquiry, your .....(Socratic Dialogue Inducing Lab)..... program is entirely in his spirit.*

According to Howard Gardner (1989):

> *If Confucius can serve as the Patron Saint of Chinese education, let me propose Socrates as his equivalent in a Western educational context – a Socrates who is never content with the initial superficial response, but is always probing for finer distinctions, clearer examples, a more profound form of knowing. Our concept of knowledge has changed since classical times, but Socrates has provided us with a timeless educational goal – ever deeper understanding.*

Rob Reich (1998) wrote:

> *The Socrates I admire can best be described as curious and confidently humble. The figure of Socrates symbolizes most powerfully the ideal of constant openness and eagerness to enter into dialogue with others. At the same time, the expectations from such dialogue are not that a final truth will be established ..... As such, the Socratic image is attractive for the purposes of modeling common inquiry and forwarding, in a sense, civic participation and engagement. Similarly, I admire the legacy of the Socratic method for its pedagogical potency to develop analytical skills and a philosophical habit that should prove invaluable in a modern democracy.*

In SDI Labs students collaborate in groups of four to:

1. Perform (often predict and then perform) simple hands-on experiments involving a BODY at rest or in motion.

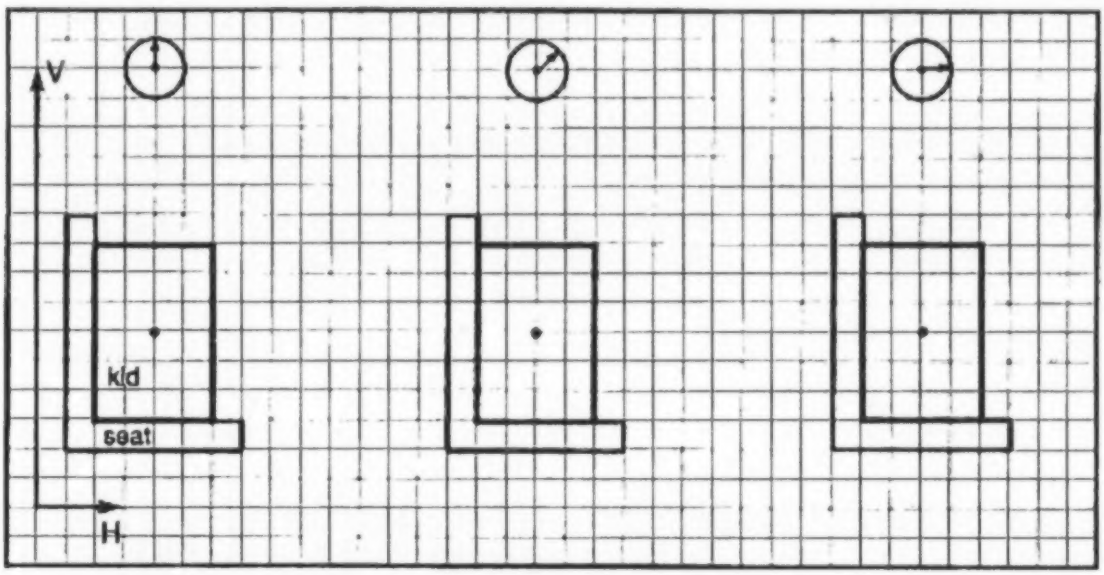
2. Draw "snapshot sketches" at sequential clock-readings showing (a) color-coded vectors to indicate ALL the forces acting ON the BODY - labeled as $\mathbf{F}_{\text{on A by B}}$, where A is the BODY and B is some other interacting body; (b) color-coded velocity and acceleration vectors "if they exist."

3. As the experiments proceed, discuss with other students and then write down answers to questions that probe for reasoning skills and basic conceptual understanding of Newton's laws. The question format is such as to require rather complete explanations, justifications, and/or sketches and not simply yes-or-no answers.

4. If stumped or confused on any of the above (after serious effort and discussions with other students) engage in Socratic dialogue with an instructor after signaling for help.

For example, in an SDI Lab on Newton's Second Law (Hake, 1998c) students are presented with this (thought) experiment:

A LOT OF PEOPLE WORRY WHEN THEIR KIDS DON'T FASTEN THEIR SEAT BELTS.
BUT IT'S NEVER BOTHERED ME A BIT.
HECK! WHEN I HIT 90 ON THE INTERSTATE THEY JUST STAY PINNED TO THEIR SEATS.!!



A. Recalling your work in SDI #1, can a truck driver pin a kid to her seats by driving his truck at a very high constant velocity **v** as suggested in the cartoon above? {Y, N, U, NOT}

{SDI Lab Rule #11: "The lab manual questions are designed to help you THINK about the experiments and how they relate to Newton's laws. You will often be asked to predict the outcome of an experiment and then perform that experiment. A curly bracket {.....} indicates that you should ENCIRCLE O a response within the bracket and then, we INSIST, briefly EXPLAIN or JUSTIFY your answers in the provided on these sheets. The letters {Y, N, U, NOT} stand for {Yes, No, Uncertain, None Of These}."}

BEST COPY AVAILABLE

B. If you were a truck driver and wished to pin a kid to her seat (by control of the truck motion) what might you do? (Three time-sequential snap-shot sketches with force **F**, velocity **v**, and acceleration **a** vectors and clocks are worth 10 terawords.) [HINT: It may help to consider the horizontal motion of a disk in your hand.]

Videotape PST1-4a shows Pat, Mary, June, and Doug tackling the above questions. After discussing question "A" regarding an earlier disk-carry experiment, they correctly decide that a truck driver *could not* pin a kid to her seat by driving his truck at a very high constant velocity **v**. They encircle "N" and justify their choices in writing in their lab manuals. Moving on to question "B", the students finally conclude that the driver *could* pin a kid to her seat by giving the bus a constant forward acceleration. They correctly draw snapshot sketches showing $\mathbf{v}_{kid}$ increasing with time; $\mathbf{a}_{kid}$ = constant $\neq 0$; equal and opposite vertical forces $\mathbf{F}_{\text{on kid by seat}}$ and $\mathbf{F}_{\text{on kid by Earth}}$; and a constant *forward* horizontal force $\mathbf{F}_{\text{on kid by seat}}$. Mary also shows a *backward* horizontal "pinning force" $\mathbf{F}_{\text{on kid}}$, thinking it's the "force due to acceleration."

Socrates: *Now you have here* **F** *on kid by seat. That's great, but I'm really worried about that force ..... (points to force on the kid in the backwards direction) .... is that really there?*

Mary: Well, it's gotta be...that's what's pin'n it back.

Doug: Not in the first part where there's no.....

Mary: (excitedly) NO!! IT'S NOT!!! IT'S NOT THERE!!

But Doug maintains otherwise: "it's there ..... it's $\mathbf{F}_{\text{on seat by kid}}$". June explains correctly that "it exists by Newton's Third Law but we're not concerned with... (the seat)." Mary concludes "that's tricky!" Socrates agrees.

As for all SDI lab experiments, the selection and phrasing of Socratic questions such as "A" and "B," and the activities surrounding them have been developed by (a) *qualitative* research (e.g., videotape analysis, student interviews, instructor discussions) extending over many years, and (b) long-term classroom use, feedback, assessment, research analysis, and redesign. (Wilson & Daviss, 1994)

The analysis of such videotapes has indicated the ways students tend to think about mechanics topics such as "pinning a kid to her seat" and prompted gradual improvements in SDI labs so to more effectively guide students to construct their understandings in accord with the Newtonian view - "scientific constructivism" (Redish, 1999).

BEST COPY AVAILABLE

Complementarity of Qualitative and Quantitative Research

Over a ten-year period at Indiana University, SDI labs were integrated into courses in which lectures, discussions, and exams emphasized conceptual understanding and interactive engagement. Lectures usually employed a standard textbook and back-of-chapter problem assignments, and discussions were devoted to cooperative group problem solving with Socratic guidance. The courses enrolled a total of 1263 students (primarily pre-med and pre-health professionals) and achieved an average <g> on the conceptual Halloun-Hestenes tests of 0.60 (Hake, 1998b), considerably higher than the average <g> = 0.47 of the other interactive-engagement courses considered in the survey (Hake, 1998a,b).

Thus the *qualitative* research which has improved SDI labs has contributed to their effectiveness as shown by the *quantitative* survey results. Then too:

a. The Halloun-Hestenes tests used for the survey were themselves developed by painstaking *qualitative* research involving the analysis of students' verbal responses to open-ended, conceptually-oriented questions.

b. The Maryland, Montana, Rennselaer/Tufts, and North Carolina State groups referred to above are examples of physics-education-research teams noted for their synergistic use of both *quantitative* and *qualitative* research methods.

c. A critical review and listing of physics-education research articles over the past four decades (McDermott & Redish, 1999) shows a mix of mutually supportive *quantitative* and *qualitative* work. (Largely ignored by the physics and education communities.)

However "paradigm peace" has not yet been achieved in physics-education research. For example:

(a) Skepticism regarding the utility of *quantitative* research for the design of instructional materials is sometimes expressed (Pride, Vokos, and McDermott, 1998).

(b) For many research physicists the term "*qualitative* research" is an oxymoron.

(c) Some "radical constructivists" are uncomfortable with quantitative tests such as the FCI that fail to reward students for the construction of understandings that do not coincide with those of professional physicists.

(d) It has been argued (van Aalst, 2000) that from the standpoint of the history and sociology of science, PER "produces knowledge that is qualitatively (especially ontologically) different from knowledge produced by physics research, and to represent it as a subfield of physics ..... [as does Redish, 1999 (and the present author)], is ..... a distortion."

(e) It can be inferred from the thesis of the McGinn & Roth, 1999 (who would seem to qualify as "antinatural critical theorists" in Gage's taxonomy) that PER as described above is irrelevant for preparing students for "competent scientific practice" because it is disconnected from "authentic science" as revealed by "empirical research in science and technology studies."

Prediction for the Year 2009

On the basis of (a) the present evidence for the effectiveness and complementarity of quantitative and qualitative PER, (b) the present state of PER (McDermott & Redish, 1999), and (c) increasing interdisciplinary synergy [fostered by e.g., the web (Hake, 1999b; Rochelle & Pea, 1999; Pea, 2000) and organizations such as AERA (< http://www.aera.net >, witness this meeting) and AAHE < http://www.aahe.org/ >], I shall predict that for PER, and possibly even education research generally, there will be "a productive rapprochement of the paradigms" by the year 2009, in accord with Gage's scenario #2. Some will follow paths of pragmatism or "Popper's piecemeal social engineering" to this paradigm peace, as suggested by Gage. However most will enter onto this "sunlit plain" from the path marked "scientific method" as practiced by most research physicists:

(1) "EMPIRICAL: Systematic investigation ..... (by *quantitative*, *qualitative*, or any other means) ..... of nature to find reproducible patterns in the structure of things and the ways they change (processes).

(2) THEORETICAL: Construction and analysis of models representing patterns of nature." (Hestenes, 1999).

(3) "Continual interaction, exchange, evaluation, and criticism so as to build a ..... community map" (Redish, 1999). The latter crucial feature of the scientific method has also been emphasized by Ziman (1978), Cromer (1997), Gere (1997), Gottfried & Wilson (1997), and Newton (1997).

References

Arons, A.B. (1990). *A Guide To Introductory Physics Teaching*. Wiley. [Reprinted with minor updates in *Teaching Introductory Physics* (Wiley, 1997).]

Beichner, R., Bernold, L., Burniston, E., Dail, P., Felder, R., Gastineau, J., Gjertsen, M., Risley, J. (1999). Case study of the physics component of an integrated curriculum. *Physics Ed. Res.*, supplement 1 to the *Am. J. Phys. 67*(7), S16-S24.

Bernhard, J. (1999). How Long-lived is Post-Course Understanding of Mechanics Concepts? Submitted to *Phys. Teach.*; on the web at < http://www.du.se/~jbe/fou/didaktik/papers/fixed.html >.

Bloom, B.S. (1984). The 2 Sigma Problem: The Search for Methods of Group Instruction as Effective as One-to-On Tutoring. *Educational Researcher 13*(6), 4 -16.

Bransford, J.D., Brown, A.L., Cocking, R.R., eds. (1999). *How People Learn: Brain, Mind, Experience, and School.* Nat. Acad. Press; on the web at
< http://www.nap.edu/readingroom/enter2.cgi?0309065577.html >.

Cohen, J. (1988). *Statistical Power Analysis for the Behavioral Sciences*. Lawrence Erlbaum, Second Edition.

Cromer, A. (1997). *Connected Knowledge*. Oxford University Press.

Cummings, K., Marx, J., Thornton, R., Kuhl, D. (1999). Evaluating innovations in studio physics. *Physics Ed. Res.*, supplement 1 to the *Am. J. Phys. 67*(7), S38-S44.

Francis, G.E., Adams, J.P., Noonan, E.J. (1998). Do They Stay Fixed? *Phys. Teach. 36*(8), 488-491.

Gage, N.L (1989). The Paradigm Wars and Their Aftermath: A "Historical" Sketch of Research on Teaching Since 1989. *Educational Researcher 18*(7), 4-10.

Gardner, H. (1989). The Academic Community Must Not Shun the Debate Over How to Set National Educational Goals. *The Chronicle of Higher Education* 8 November

Giere, R.N. (1997). *Understanding Scientific Reasoning*. Holt, Rinehart, and Winston.

Gottfried, K. & Wilson K.G. (1997), Science as a cultural construct. *Nature 386*, 545-547.

Greene, R.L. (1999) Alternative Conception. Letter to the editor, *Phys. Teach. 37*(9), 518.

Hake, R.R. (1987). Promoting student crossover to the Newtonian world. *Am. J. Phys. 55*, 878-884.

Hake, R.R. (1991). My Conversion To The Arons-Advocated Method Of Science Education. *Teaching Education 3*(2), 109-111, soon to be placed on the web at < http://physics.indiana.edu/~hake/ >.

Hake, R.R. (1992). Socratic Pedagogy in the Introductory Physics Lab. *Phys. Teach. 30*, 546-552; an updated version is on the web at < http://physics.indiana.edu/~sdi/ >.

Hake, R.R. (1996). Errors in the Normalized Gain, unpublished, available on request.

Hake, R.R. (1998a). Interactive-engagement vs traditional methods: Asix-thousand-student survey of mechanics test data for introductory physics courses. *Am. J. Phys. 66*(1), 64-74; on the web at < http://www.physics.indiana.edu/~sdi/ >

Hake, R.R. (1998b). Interactive-engagement methods in introductory mechanics courses, submitted to *Phys. Ed. Res.*, supplement to *Am. J. Phys.*; on the web at < http://www.physics.indiana.edu/~sdi/ >.

Hake, R.R. (1998c). SDI Lab #2, *Newton's Second Law*. On the web at < http://www.physics.indiana.edu/~sdi >, teacher's guide (password protected) soon to appear at < http://galileo.harvard.edu/index.html > under "Hands-on methods"/"SDI Labs"/ "Resources"/"Teachers' Guides".

Hake, R.R. (1998d). Interactive-engagement vs Traditional Methods in Mechanics Instruction. *APS Forum on Education Newsletter*, Summer 1998, p. 5-7, also at < http://www.physics.indiana.edu/~sdi >.

Hake, R.R. (1999a). Analyzing change/gain scores. Unpublished, on the web at < http://www.physics.indiana.edu/~sdi >.

Hake, R.R. (1999b). What Can We Learn from the Biologists About Research, Development, and Change in Undergraduate Education? *AAPT Announcer 29*(4), 99 (1999); available on the web at < http://www.physics.indiana.edu/~hake > as [WhatLearn.pdf, 1/31/2000, 204K].

Hake, R.R. (2000). What Can We Learn from the Physics Education Reform Effort?" ASME Mechanical Engineering Education Conference: "Drivers and Strategies of Major Program Change," Fort Lauderdale, Florida, March 26-29, 2000; on the web at < http://www.physics.indiana.edu/~hake > as [ASME.pdf, 3/27/00, 436K].

Halloun, I. & Hestenes D. (1985a). The initial knowledge state of college physics students. *Am. J. Phys. 53*, 1043-1055.

Halloun, I. & Hestenes D. (1985b). Common sense concepts about motion. *Am. J. Phys. 53*, 1056-1065.

Halloun, I., Hake, R.R., Mosca, E.P., Hestenes, D. (1995). Force Concept Inventory (Revised, 1995), password protected at < http://modeling.la.asu.edu/modeling.html >.

Hestenes, D., Wells M., Swackhamer, G. (1992). Force Concept Inventory. *Phys. Teach. 30*, 141-158.

Hestenes D. & Wells, M. (1992). A Mechanics Baseline Test. *Phys. Teach. 30*, 159-166, password protected at < http://modeling.la.asu.edu/modeling.html >.

Hestenes D. (1999). The scientific method. *Am. J. Phys. 67*(4), 274.

Hunt, M. (1997). *How Science Takes Stock: The Story of Meta-Analysis*. Russell Sage Foundation.

Jowett, B. (1953). *The Dialogues of Plato translated into Engish with Analyses and Introductions*. 4 vols. , 4th ed. Oxford. The Jowett translation of *Meno* is on the web at < http://classics.mit.edu/Plato/meno.html >.

Morse, R.A. (1994). The Classic Method of Mrs. Socrates. *Phys. Teach. 32*(5), 276-277.

McDermott L.C. & Redish E.F. (1999). RL-PER1: Resource Letter on Physics Education Research. *Am. J. Phys. 67*(9), 755-767; on the web at < http://www.physics.umd.edu/rgroups/ripe/perg/cpt.html >.

McDermott, L.C., Shaffer, P.S., and Somers, M.D (1994). Research as a guide for teaching introductory mechanics: An illustration in the context of the Atwood's machine. *Am. J. Phys. 62*(1), 46-55.

McGinn, K.M. & Roth, W-M. (1999). Preparing Students for Competent Scientific Practice: Implications of Recent Research in Science and Technology Studies. *Educational Researcher 28*(3), 14-24.

Newton, R.G. (1997). *The Truth of Science: Physical Science and Reality*. Harvard University Press.

Pea, R. (2000). New Media Communications Forums for Improving Education Research and Practice. In E. Condliff Lagemann and L.S. Shulman (eds.) *Issues In Education Research* (Jossey-Bass, in press); on the web at < http://www.sri.com/policy/ctl/html/contexthome.htm >.

Plato (380 B.C.). *Meno.*

Pride, T. O., Vokos, S., McDermott, L.C. (1998). The challenge of matching learning assessments to teaching goals: An example from the work-energy and impulse-momentum theorems. *Am. J. Phys. 66*(2), 147-157.

Redish, E.F., Saul, J.M., Steinberg, R.N. (1997). On the effectiveness of active-engagement microcomputer-based laboratories. *Am. J. Phys. 65*(1), 45-54; on the web at < http://www.physics.umd.edu/rgroups/ripe/perg/cpt.html >.

Redish, E.F. & Steinberg, R.N. (1999). Teaching Physics: Figuring Out What Works. *Phys. Today 52*(1), 24-30; on the web at < http://www.physics.umd.edu/rgroups/ripe/perg/cpt.html >.

Redish, E.F. (1999). Millikan Lecture 1998: Building a Science of Teaching Physics. *Am. J. Phys. 67*(7), 562-573; on the web at < http://www.physics.umd.edu/rgroups/ripe/perg/cpt.html >.

Reich, R. (1998). Confusion about the Socratic Method: Socratic Paradoxes and Contemporary Invocations of Socrates. *Philosopy of Education Yearbook 1998*; on the web at < http://www.ed.uiuc.edu/EPS/PES-Yearbook/1998/reich.html >.

Roschelle, J. and Pea, R. (1999). Trajectories from Today's WWW to a Powerful Educational Infrastructure. *Educational Researcher*, June-July 1999, 22-25, 43.

Saul, J.M. (1998). *Beyond Problem Solving: Evaluating Introductory Physics Courses Through the Hidden Curriculum.* Ph.D. thesis, Univ. of Maryland.

Slavin, R.E. (1992). *Research Methods in Education.* Allyn & Bacon, 1992.

Snedecor, G.W., and Cochran, W.G. (1989). *Statistical Methods.* Iowa State Univ. Press, 8th ed.).

Springer, L., Stanne, M.E., Donovan, S. (1999). Effects of cooperative learning on undergraduates in science, mathematics, engineering, and technology: A meta-analysis. *Review of Educational Research* (in press); on the web at < http://www.wcer.wisc.edu/nise/CL1/CL/resource/R2.htm >.

Swartz, C. (2000). Buzzwords and Newspeak, editorial. *Phys. Teach. 38*(3), 134.

Swartz, C. (1994). The Classic Socratic Method. *Phys. Teach. 32*(3), 138-141.

Tobias, S. & Hake, R.R. (1988). Professors as physics students: What can they teach us? *Am. J. Phys. 56*, 786-794.

van Aalst, J. (2000). An Introduction to Physics Education Research. *Canadian Journal of Physics*, in press; on the web at < http://www.sfu.ca/~vanaalst/PER.html >.

Vlastos, G. (1990). Private communication, 9/17/90.

Vlastos, G. (1991) *Socrates, Ironist and Moral Philosopher*. Cornell Univ. Press, esp. Chap. 2, "Socrates contra Socrates in Plato."

Vlastos, G. (1994) *Socratic Studies*. Cambridge Univ. Press.

Wells, M., and Hestenes,D. (1995). A modeling method for high school physics instruction. *Am. J. Phys. 63*(7), 606-619.

Wilson, K.G. and Daviss, B. (1994). *Redesigning Education* (Henry Holt,1994), see < http://www-physics.mps.ohio-state.edu/~kgw/RE.html >.

Zeilik, M., Schau, C., Mattern, N. (1998). Misconceptions and Their Change in University-Level Astronomy Courses. *Phys. Teach. 36*(2), 104-107.

Ziman, J.M. (1978). *Reliable Knowledge: An Exploration of the Grounds for Belief in Science.* Cambridge University Press.

4/8

SE067421

U.S. Department of Education
Office of Educational Research and Improvement (OERI)
National Library of Education (NLE)
Educational Resources Information Center (ERIC)

REPRODUCTION RELEASE

(Specific Document)

I. DOCUMENT IDENTIFICATION:

Title: "Towards Paradigm Peace in Physics-Education Research," presented at the annual meeting of the American Educational Research Association, New Orleans, April 24-28, 2000; online as ref. 3 at <http://www.physics.indiana.edu/~hake>.	
Author(s): Richard R. HAKE	
Corporate Source: None	Publication Date: 2000

II. REPRODUCTION RELEASE:

In order to disseminate as widely as possible timely and significant materials of interest to the educational community, documents announced in the monthly abstract journal of the ERIC system, *Resources in Education* (RIE), are usually made available to users in microfiche, reproduced paper copy, and electronic media, and sold through the ERIC Document Reproduction Service (EDRS). Credit is given to the source of each document, and, if reproduction release is granted, one of the following notices is affixed to the document.

If permission is granted to reproduce and disseminate the identified document, please CHECK ONE of the following three options and sign at the bottom of the page.

The sample sticker shown below will be affixed to all Level 1 documents	The sample sticker shown below will be affixed to all Level 2A documents	The sample sticker shown below will be affixed to all Level 2B documents
PERMISSION TO REPRODUCE AND DISSEMINATE THIS MATERIAL HAS BEEN GRANTED BY Sample TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC) 1	PERMISSION TO REPRODUCE AND DISSEMINATE THIS MATERIAL IN MICROFICHE, AND IN ELECTRONIC MEDIA FOR ERIC COLLECTION SUBSCRIBERS ONLY, HAS BEEN GRANTED BY Sample TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC) 2A	PERMISSION TO REPRODUCE AND DISSEMINATE THIS MATERIAL IN MICROFICHE ONLY HAS BEEN GRANTED BY Sample TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC) 2B
Level 1	Level 2A	Level 2B
✓ Check here for Level 1 release, permitting reproduction and dissemination in microfiche or other ERIC archival media (e.g., electronic) and paper copy.	Check here for Level 2A release, permitting reproduction and dissemination in microfiche and in electronic media for ERIC archival collection subscribers only	Check here for Level 2B release, permitting reproduction and dissemination in microfiche only

Documents will be processed as indicated provided reproduction quality permits.
If permission to reproduce is granted, but no box is checked, documents will be processed at Level 1.

I hereby grant to the Educational Resources Information Center (ERIC) nonexclusive permission to reproduce and disseminate this document as indicated above. Reproduction from the ERIC microfiche or electronic media by persons other than ERIC employees and its system contractors requires permission from the copyright holder. Exception is made for non-profit reproduction by libraries and other service agencies to satisfy information needs of educators in response to discrete inquiries.

Signature: Richard R. Hake	Printed Name/Position/Title: Professor Richard R. Hake	
Organization/Address Emeritus Professor, Indiana University 24245 Hatteras Street Woodland Hills, CA 91367	Telephone: 818-992-0632	FAX: 818-992-0632
	E-Mail Address: <rrhake@earthlink.net>	Date: 17 March 2003